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Literature review and estimation of municipal and agricultural values of groundwater use in

TATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

LITERATURE REVIEW AND ESTIMATION OF MUNIPICAL AND AGRICULTURAL VALUES OF GROUNDWATER USE IN THE UPPER CLARK FORK RIVER DRAINAGE

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Literature Review and Estimation of Municipal and Agricultural Values of Groundwater Use in the Upper Clark Fork River Drainage

Report to the Montana Natural Resource Damage Program

by

Bioeconomics, Inc.
Missoula, MT

January, 1995

Literature Review and Estimation of Municipal and Agricultural Values of Groundwater Use in the Upper Clark Fork River Drainage

This report was prepared under my direction and control. I can testify to the opinions set forth herein and the basis and reasons therefor.

John Duffield 12/19/94

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1.0 Introduction

This report provides estimates of unit (per acre foot) values for municipal and agricultural uses of groundwater in the upper Clark Fork River and Silver Bow Creek Drainages.

A description of the groundwater contamination at issue can be found in a recent study on groundwater injury entitled "Summary and Overview: Groundwater Injury Assessment Reports Clark Fork River Basin Montana" (Montana, 1993). Aquifers under and in the near vicinity of Butte, Anaconda, and Milltown have suffered contamination which has rendered some groundwater unusable as municipal or private residential water sources.

There are a number of alternative approaches to valuing changes in the supply or availability of groundwater for municipal uses. These include: 1) marginal values derived from existing models of residential water demand, 2) market prices for water transactions, 3) cost savings over alternative sources. For agricultural uses the primary approach is to examine the contribution of groundwater to agricultural production (the factor price approach). Each of these methods is described in greater detail below. Empirical estimates of water values specific to the Clark Fork Basin are derived with each method using readily available data.

2.0 Municipal Water Values

2.1 Valuing a Marginal Change in Municipal Water Supply

2.1.1 Concepts

The most comprehensive review of the literature on municipal water values is by Gibbons (1986). She focuses on measuring the value of an incremental change in water supply as illustrated in Figure 2-1. The latter provides an estimate of the consumer surplus (net willingness to pay over and above the given price or area ABC in Figure 2-1) that municipal water customers realize from an increment in water supply. Note that this approach assumes that the water is essentially "free" to the municipality. If the municipality in fact has to purchase water rights to obtain the water, this unit price needs to be added to the consumer surplus estimate. Market prices for water rights are discussed in the next section.

This approach to groundwater valuation could be applicable if a groundwater resource was used to provide an increment in supply (such as from Q1 to Q2 in Figure 2-1). Note that unless supply is increased to Q2, demand exceeds supply at price P1 (there is a water "shortage"). If a water shortage has existed in the past or will exist in the future because of groundwater contamination, this approach provides a measure of the lost use value.

In order to estimate the lost use area ABC one would need to know the change in supply (Q2 minus Q1), the price and the shape and location of the demand curve (the line passing through A and B in Figure 2-1). Obviously the larger the reduction in use and the steeper

(more inelastic) the demand curve, the larger is the unit (per acre foot or per cfs) consumer surplus loss. To date there are no estimates of the shape or location of the municipal demand for water in the Clark Fork Basin communities. However, Young et al. (1972) provide a method for estimating the area ABC using a) an assumed constant price elasticity of demand (through the region of the supply shift) based on the economics literature, b) the actual price for municipal water for the community of interest, and c) an assumed (or actual) reduction in municipal water supply (the extent of the "shortage"). It should be noted that implicitly (in Figure 2-1) it is also assumed that marginal and average costs are constant and equal to price.

In the remainder of this section we provide a brief mathematical description of Young's method, a review of the economics literature on the elasticity of demand for residential water uses and an estimate of the marginal value of municipal water in the Clark Fork Basin using this method.

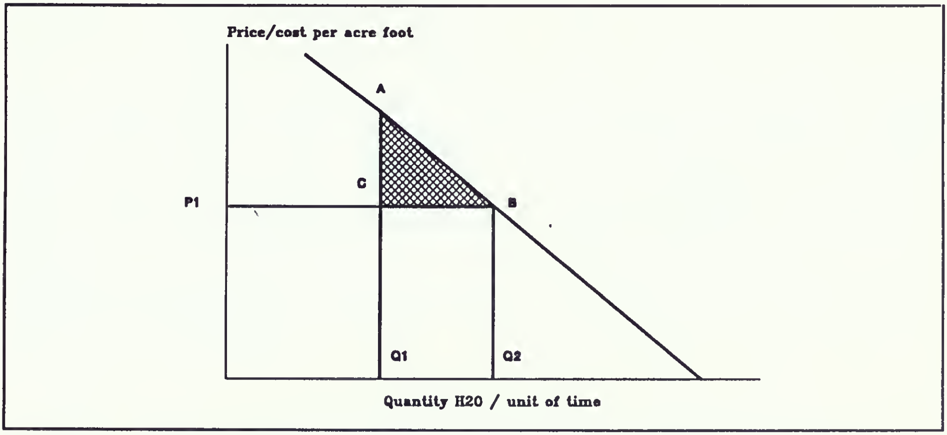

Figure 2-1. Consumer surplus for a given municipal water price and quantity change.

2.1.2 Estimating Marginal Municipal Water Values using Elasticity of Demand

Following Young (1972), for a given change in water supply (from Q_1 to Q_2) the total value of water is equal to the area under the demand curve. This area can be described mathematically as

$$TV = \int_{Q_1}^{Q_2} P(q)\ dq \tag{1}$$

If the price elasticity of demand is constant over the range from Q_1 to Q_2, and is not equal to -1, and a point on the demand curve is known, the above equation can be rewritten as

$$TV = \left[\frac{P\ Q_2^x}{1 - x}\left(\frac{Q_2}{Q_2^x} - \frac{Q_1}{Q_1^x}\right)\right] \tag{2}$$

Where:

P = price per acre foot of water
Q2 = quantity demanded (acre feet) at P
Q1 = new quantity
x = 1/abs(price elasticity of demand)

The area described by equation 1 above is shown graphically in Figure 2-1, as defined by A B Q2 Q1. The portion of this area which represents the consumer surplus accruing to municipal water customers is the area above the municipal price level (P1) and below the demand curve. This is the triangle described by ABC in the graph. This area represents net willingness to pay for municipal water, above what one must pay (the marginal price). The total value estimate from equations 1 or 2 can be translated into a net willingness to pay (NET WTP) value per acre foot by dividing the total value by the change in quantity (Q2-Q1) and subtracting out the price per acre foot charged for municipal water (Equation 3). By assumption price is equal to average and marginal costs.

$$NET\ WTP = \left[\frac{TV}{(Q_2 - Q_1)}\right] - P \tag{3}$$

The calculation of net WTP from equations 2 and 3 can be accomplished using a percentage change in quantity rather than a specific volume reduction. For estimating a percentage change, it is not necessary to know the initial quantity consumed at price P. Equations 4 and 5 show the formula for calculating net WTP for a percentage decrease in use (A 10% decrease in water quantity was used in the application described below.)

$$TV = \left[\frac{P}{1-x}\left(1 - \frac{(1-r)}{(1-r)^{x}}\right)\right] \tag{4}$$

$$NET\ WTP = \left[\frac{TV}{r}\right] - P \tag{5}$$

Where: r = Percentage reduction expressed as a decimal (10% reduction- r=.10)

2.1.3 Literature Estimates of Price Elasticity of Demand

In order to utilize Young's method, one needs to have an estimate of elasticity of demand. This responsiveness, or price elasticity of demand, represents the percentage change in quantity demanded from a 1% change in the price of the water. Gibbons (1986) noted that several studies (Danielson, 1977; Howe and Linaweaver, 1967; Young, 1973) have found that estimates of summer price responsiveness are more elastic than those of winter. This makes intuitive sense as summer residential consumption is significantly greater than winter, due to outdoor water uses such as lawn watering. It is easier to reduce consumption of water for lawn watering than for drinking, cooking, and bathing. Therefore, the price responsiveness of demand for water tends to be more elastic in the summer than in the winter.

There have been a number of studies of municipal water demand which provide estimates of the price elasticity of demand for residential water use. Two somewhat overlapping surveys of this literature are provided by Wong (1972) and Gibbons (1986). These two surveys provide a range of price elasticity estimates. Wong cites 18 separate estimates and Gibbons provides citations for an additional 5 elasticity estimates. Additionally, Colander and Haliwanger (1979) provide refinements on Young's (1973) estimates and Renzetti (1992) provides his own estimates of residential price elasticities.

The overall range of elasticity estimates in the literature varies between -0.02 and -1.24. The majority of the estimates in this range are based on cross-sectional rather than time-series data. Colander and Haliwanger (1979) argue that in the case of demand for municipal water time-series elasticity estimates are more appropriate and tend to be more inelastic than cross-sectional elasticities. Time-series estimates are more appropriate, they point out, because cross-sectional data capture long-run structural differences and are most useful for estimating long-run demand curves useful in long range planning. For an established community, however, adjustment to water price changes is much more costly (one does not buy a new house with a smaller lawn because the price of water increases by 10%). For the purposes of examining the impact of water shortages on a given community, elasticity estimates based on time series data may be more appropriate.

Table 2-1 shows estimates of price elasticity of demand derived from time-series data as presented in Gibbons (1986). The range of these elasticities is from -0.02 to -0.63.

Table 2-1. Estimates of price elasticity of demand for municipal water derived from time-series data.

Study and date	Location / estimation notes	Price elasticity estimate
Wong (1972)	Chicago / city sample	-0.02
Wong (1972)	Chicago / suburbs sample	-0.28
Young (1973)	Tucson / sample 1 (1946-65)	-0.62
Young (1973)	Tucson / sample 2 (1965-71)	-0.41
Danielson (1977)	Raleigh, NC	-0.27
Billings and Agthe (1980)	Tucson / log specification	-0.39
Billings and Agthe (1980)	Tucson / linear specification	-0.63

Source: Gibbons (1986)

2.1.4 An Application of Young's Method (Gibbons 1986)

Gibbons (1986) provides an example of estimated marginal values for municipal water use based on published elasticities of demand for Tucson, Raleigh, and Toronto (Table 2-2). She uses actual prices for these localities and assumed reductions in supply ranging from 1/4 to 2 ccf/month (100 cubic feet per month) and also for a 10 percent reduction in supply.

The values she computes range from $17/acre foot to $105 depending on the season and locality for the 10 percent reduction. Her estimates are in 1980 dollars; inflating these to 1993 price levels using the CPI-U generates a value range of $30 to $184. Note that the prices reported by Gibbons in Table 2-2 are in dollars per ccf; as an example of prices in dollars per acre foot the value for Raleigh in 1993 dollars is $968. This is in the same range as current prices for municipal water at Butte ($1027/af for an assumed average monthly consumption of 2500 cubic feet)(Table 2-3).

2.1.5 Marginal Values for Municipal Water in the Clark Fork Basin

It is possible to use Equations 2 and 3 to estimate a plausible range of municipal water values for a city with a municipal water charge, like Butte. While no elasticity for municipal water has been estimated for the upper Clark Fork communities (and data of sufficient quantity and quality is not available for such an estimation), the city of Billings, Montana was found to have a long enough history of municipal water prices and metered demand to allow the estimation of a price elasticity of demand for this municipality.

Table 2-2. Marginal Values for Residential Water Demand

Locality and date of data	Season	Price (1980 dollars/ ccf)*	Elasticity	Average consumption (ccf/house-hold/ month)	Marginal water values (1980 dollars/acre-foot)				
					Reductions from the average monthly consumption (ccf)				10 percent reduction
					¼	½	1	2	
Tucson, Ariz., 1979	Winter	0.72	−0.23	9.44	19	40	89	225	82
	Summer	0.83	−0.70	16.43	4	8	17	35	28
Raleigh, N.C., 1973	Winter	1.27	−0.305	7.82	30	64	142	358	105
	Summer	1.23	−1.380	8.81	6	11	24	—	21
Toronto, Ont., 1967	Winter	0.79	−0.75	5.30	11	23	51	124	25
	Summer	0.79	−1.07	6.55	6	13	27	—	17

Note: Dashes = not applicable.

Sources: Leon E. Danielson, "Estimation of Residential Water Demand," Economics Research Report no. 39 (North Carolina State University at Raleigh, October 1977); Angelo P. Grima, *Residential Water Demand: Alternative Choices for Management* (Toronto, Ontario, University of Toronto Press, 1972); Charles W. Howe and F. P. Linaweaver, Jr., "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure," *Water Resources Research* vol. 3, no. 1 (first quarter 1967) pp. 13–32; Robert A. Young, "Price Elasticity of Demand for Municipal Water: A Case Study of Tuscon, Arizona," *Water Resources Research* vol. 9, no. 4 (August 1973) pp. 1068–1072.

*All prices have been converted to 1980 dollars by using the fixed-weighted GNP price index; ccf = hundred cubic feet.

Annual reports filed by Billings with the Montana Public Service Commission were examined for the years 1976-1990. From these reports, the number of metered hookups on the Billings system and the total annual metered consumption were recorded. Municipalities also are required to file notices of water tariffs with the Montana PSC. These water rates were examined for the 1976-1990 period, and annual marginal rates were calculated for the fifteen years. In addition to the consumption and price data for the fifteen years, total May through September rainfall (the months with significant consumption due to lawn watering) in Billings and average per capita personal income for the Billings Metropolitan Statistical Area (MSA) were recorded for the sample years. A time series model was then estimated using the following variables: average monthly consumption for metered customers for the year measured in ccf (hundred cubic feet per second), the price for water for the year measured in cents per ccf divided by per capita personal income for that year, and the total May through September rainfall for Billings in inches. Table 2-3 shows the time series data for Billings that was used in the modeling.

Table 2-4 shows the estimated municipal water demand models for Billings. The general specification here uses average metered consumption as the dependent variable and rainfall and price over income as independent variables. All variables for an estimated linear model have highly significant coefficients of the expected signs. The adjusted R^2 of 0.51 indicates that a significant proportion of the variation in the dependent variable (consumption) is explained by the model. An alternative double log specification also provides a good fit with significant coefficients on all variables (Table 2-4). The estimated price elasticity of demand derived from these models is not very sensitive to alternative specification of functional form. The linear specification yielded a slightly more conservative (elastic) estimate of price elasticity of demand (Table 2-4), therefore the linear specification was used in the following calculations.

The estimated price elasticity of demand, at the means of the dependent and price variables, is -0.2393. This estimated elasticity is within the range of elasticities reported in Table 2-1.

Table 2-3. Time-series data on municipal water prices, demand, and summer rainfall for Billings, Montana: 1976-1990.

Year / statistic	Ave. Monthly Consumption (ccf)	Average price per ccf paid by residential customers	Average per capita personal income, Billings (MSA)	May-September rainfall (inches)
1990	24.00	1.01	16,547	6.00
1989	29.50	0.95	15,768	4.54
1988	25.50	0.99	14,757	8.63
1987	24.98	1.00	14,109	6.95
1986	23.51	1.02	13,634	9.68
1985	26.22	0.99	13,494	4.95
1984	25.25	1.00	13,194	6.15
1983	23.79	1.02	12,485	6.65
1982	25.21	0.80	12,059	10.23
1981	23.55	0.71	11,372	13.89
1980	28.03	0.52	10,211	6.75
1979	25.17	0.54	9,357	7.41
1978	26.78	0.38	8,387	10.87
1977	27.40	0.35	7,537	3.46
1976	26.58	0.35	6,730	7.88
Variable Means	25.699	0.7997	11,977.87	7.607
Mean of computed variable (Price/income)				6.3021 -05

Table 2-4. Estimated model of Price Elasticity of Demand for Municipal Water Consumption, Billings, Montana.

Variable / Statistic	Linear specification	Double log specification
	Estimated Coefficient (t-stat)	Estimated Coefficient (t-stat)
Intercept	33.89 (16.32)**	1.4592 (2.148)*
Marginal Price	-92099 (-3.161)**	-0.2021 (-2.922)**
Rainfall	-0.314 (-2.633)*	-0.0877 (-2.505)*
Sample size	15	15
Adjusted R^2	0.514	0.502
Price elasticity of demand evaluated at the variable means	-0.23926	-0.2021

Dependent variable: Average metered consumption / month (ccf).

* significant at the 95% level of confidence

** significant at the 99% level of confidence

Table 2-5 shows the estimate of the marginal value per acre foot of municipal water for Butte and Anaconda using the methodology of Young et al., assuming that the estimated price elasticity for Billings is also appropriate for Butte and Anaconda. The basic finding is that the estimated marginal value per acre foot of municipal water is $208.00 in Butte, $141.00 in Anaconda and $66.00 in Milltown . These estimates are based on the current metered water rates charged in Butte and Anaconda and the flat rate charged in Milltown, the estimated price elasticity of demand for Billings of -0.2393, and an assumed 10% reduction in consumption. It should be noted that the estimated marginal value is quite sensitive to the size of the reduction in consumption being modeled. The larger the reduction in consumption, the greater the marginal value per acre foot. This makes intuitive sense, since greater reductions in consumption cut into more and more necessary (and thus more highly valued) uses of the water.

Table 2-5. Estimate of the marginal value of municipal water for Butte and Helena.

City	Marginal price / a.f.	Elasticity	M.V. per Acre foot (1993 $)
Butte	$ 828 [a]	-0.2393	$ 208
Anaconda	$ 562 [b]	-0.2393	$ 141
Milltown	$ 261[c]	-0.2393	$ 66

Note: calculations are based on an estimated 10% decrease in consumption by households

[a] Based on an average monthly consumption of 25 ccf priced at $4.032/ccf for the first 5 ccf, $2.032/ccf for the next 5 ccf and $1.90/ccf for the next 40 ccf. The $1.90/ccf consumption block is where the marginal reduction is assumed to occur.

[b] Based on an average monthly consumption of 25 ccf priced at $1.645/ccf for the first 6.6 ccf, $1.53/ccf for the next 4.4 ccf and $1.29/ccf for the next 40 ccf. The $1.29/ccf consumption block is where the marginal reduction is assumed to occur.

[c] Based on a flat fee of $15 per month for residential hookups, and an average assumed consumption of 25 ccf per month.

2.1.6 Plausible Upper Limit for Marginal Groundwater Values

As Gibbons noted, the marginal value of municipal water varies greatly depending on how much the supply is constrained; when the supply is so constrained that there are shortages of drinking water the marginal value will be quite high. There are several ways to examine the marginal value at the upper end of the demand relationship. As an example, the price of bottled drinking water in Missoula is $4.00 for five gallons or $0.80 per gallon. This implies a price of $260,000 per acre foot; of course no one would buy an entire acre foot of drinking water.

Another perspective is provided by the average costs some individuals are willing to pay for a household groundwater well. As an example, the Pattee Canyon area just east of Missoula has many residential wells in the 500 foot range and some even approaching 1000 feet (personal communication, Dennis O'Donnell, area resident). Given the relatively low consumption of residential water users, the costs of drilling and operating these wells implies a high willingness to pay.

An approximate estimate of the costs of these deep wells is derived as follows. There are 62 registered residential wells in a six section area of Pattee Canyon with an average total well depth of 235 feet and an average pumping depth of 210 feet. Many of these wells are located in the alluvial gravels of Pattee Creek, where wells are significantly shallower than in other portions of the area. An analysis of a subset of 9 wells in 3 of the 6 sections which are not located in the creek bottom shows much deeper wells. The average depth for these 9 wells was 473 feet with an average pumping level of 424 feet. One residential well in this area is 960 feet deep. The amortized and depreciated costs of pumping water from a well 900 feet deep, for typical residential consumption, could run in the range of 2000-3000 dollars per acre foot.

2.2 Estimates of municipal water value based on water rights transfer

A second method of gathering information on the value of municipal water supplies is through examination of transfers of water rights. Gibbons (1986) notes that where information on purchases of water rights are available the prices paid can be used to calculate average willingness to pay.

Not surprisingly, active markets in municipal water rights have arisen in areas with rapidly growing populations and limited water supplies. Colorado towns on the eastern slope of the Rockies and towns in the arid southwest such as Phoenix, Tucson, and Albuquerque all have purchased water rights for municipal uses in recent years.

An active market for water rights has not developed in Montana, possibly because until very recently one could still file for the use of unappropriated water in all regions of Montana. Groundwater and surface water were generally available for the cost of filing and development. Montana is now in a transition period as several major basins have been closed to water right filing. The Madison, Jefferson and Teton Basins have been permanently closed and the entire Upper Missouri River Basin above Moroney Dam is temporarily closed. The Upper Clark Fork Basin was temporarily closed by the Montana Legislature in 1991. A water management plan for this area is being developed, with the temporary closure to terminate on July 1, 1995.

With basin closures, water rights for new uses must be obtained from existing users. Over time this will likely lead to the development of a water market in closed basins. Evidence on the likely level of prices is limited. However, Montana Department of Fish, Wildlife and Parks has in recent years leased water for instream flow in the Yellowstone Basin - which is not closed. One lease costing $7,500 a year on Mill Creek is for about $3/acre foot. Another lease for $12,000/year has a cost per acre foot of $56, though this price includes the cost of monitoring the water allocation on this stream (Liter Spence, personal communication).

Since the dominant use of water in all Montana basins is irrigated agriculture, it is expected that future prices will be dominated by the net value of water to irrigators (Duffield, 1991). These values vary with crop and region, and are estimated to be on the order of $40/acre foot for surface water used for irrigated alfalfa hay in the Upper Clark Fork Basin (see the discussion in Section 3.1 below). This value ($40/af) may be a conservative estimate of price because of the reluctance of agricultural water users to participate in market transactions or in any way risk the legal viability of their water right. There may also be legal and institutional barriers to transactions that will result in prices in excess of the net value of water to irrigators. Irrigators may be reluctant to quit irrigating, but may be willing to become more efficient water users. Therefore, some quantities of surface water rights may be available for the cost of improved efficiency in irrigation systems. For example, the long-run average cost difference between a flood irrigation system and a wheelline sprinkler system in on the order of $15/acre foot and the difference between flood and a center pivot system is about $23/acre foot (Duffield, 1991). The net cost of the saved water depends on the efficiency improvement achieved.

Markets for water rights are spatially constrained due to high transportation costs and possible legal barriers to interstate water transfers. Water right prices from elsewhere in the west are not directly applicable to Montana. Furthermore, DOI regulations provide that other valuation methodologies should be used in damage assessments where the market for a resource is not reasonably competitive. Nonetheless, we will briefly discuss water right transfer prices from elsewhere in the west by way of example.

Gibbons cites a purchase of water rights for municipal use in Colorado which cost $300 per acre foot in 1981, or approximately $475 /acre foot in 1992 dollars. Duffield et al. (1991) cite several 1989 water market price levels in the western U.S. ranging from approximately $94 to $475 per acre foot (1992 dollars). It is our understanding that open access to groundwater has ended in the Boise area and that a market for this resource is developing.

2.3 Groundwater Values Based on Cost Savings over Substitute Sources

2.3.1 Overview

The method of section 2.1 has application to valuing lost use of contaminated groundwater if the contamination results in a water shortage. More commonly, a substitute source of water supply will be used - such as a surface resource or groundwater from an uncontaminated aquifer. In this case there may be an economic loss if the cost of using the groundwater in its uncontaminated state is lower than the cost of the substitute resource.

Figure 2-2 (the area bounded by P1, A, B and P2) provides a graphical measure of the possible cost savings of a water resource available at price P2 compared to the existing price P1. There is also a loss associated with the foregone consumer surplus associated with the increased use from Q1 to Q2.

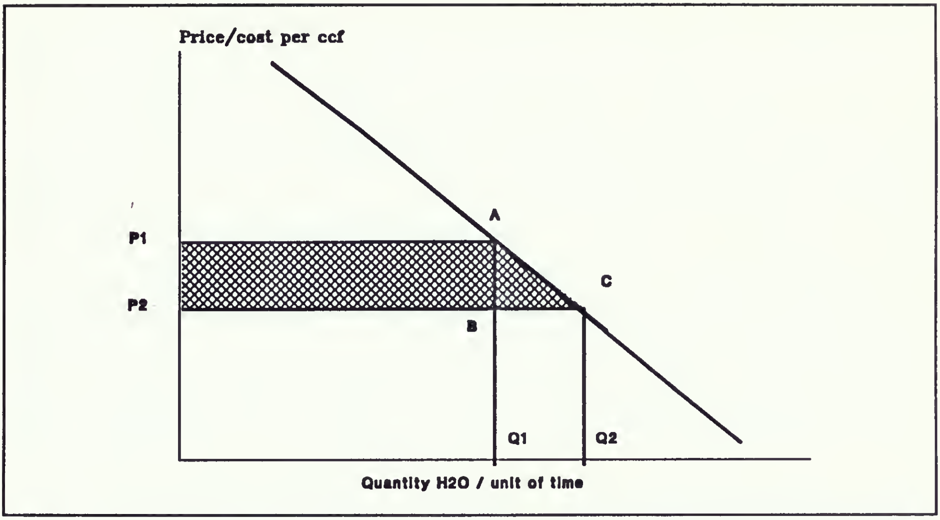

Figure 2-2. Graphical area representing the economic loss associated with using a resource available at average cost of P1 compared to P2.

There are a number of possible permutations of resources that might indicate cost savings including: 1) due to the presence of a contaminated aquifer, individuals may connect to a (more expensive) municipal system rather than use individual groundwater wells, 2) a contaminated local aquifer may force a municipality to use other more expensive surface or groundwater resources.

In the following sections we examine some of the readily available data to see if either of these situations are plausible for the Upper Clark Fork Basin.In the next section we summarize data on groundwater wells in the Upper Clark Fork Basin. This data is used to estimate average costs of residential and municipal wells. Information on wells is aggregated in order to find the average total depth, pumping depth, casing size, casing type, and water yield for the area. These aggregate averages were then used to calculate the average cost of drilling and operating wells in the areas. These average costs per acre foot can then be compared to average costs of existing municipal systems. Note the maintained hypothesis of average cost pricing implies that average costs are given by the price charged per acre foot by municipal water companies. We also assume that in the absence of a contaminated aquifer when a residential groundwater well was cheaper than connecting to the municipal system a groundwater well would have been used.

2.3.2 Groundwater well data

The Montana Bureau of Mines and Geology maintains a database of existing groundwater wells in Montana. A subset of this database was obtained from the bureau which contained all wells within a geographic rectangle defined by townships 3 north to 8 north and ranges 7 west to 11 west (Figure 2-3). This rectangle includes the Upper Clark Fork Basin from approximately Deer Lodge to and including Butte. This database contained 2,626 registered groundwater wells. For each well the following information was given, where available: township, range, section, total depth, pumping depth, rated capacity, casing diameter, type, and depth, static water line, water use, year drilled, and information on screen perforations.

The location information in this database allowed each well to be assigned to a specific aquifer area which was somewhat larger than the areas containing the contaminated groundwater plumes (Figure 2-3). Three aquifer areas were identified: Anaconda, Butte, and Rocker. The Butte area also contained the Montana Pole site. Table 2-6 shows the aerial extent of the estimated injured groundwater (from Table 1-2, Montana, 1993) as well as the extent of aquifer area used in this analysis. The SAS command file in Appendix A shows the exact sections assigned to each area.

Table 2-6. Areal extent of groundwater injury and portion of aquifer used in the analysis

Resource Area	Extent of contaminated Aquifer (square miles)	Extent of aquifer analysis area (square miles)
Butte (includes Montana Pole)	9.07	19.0
Anaconda	<25.0	76.0
Rocker	0.03	4.0

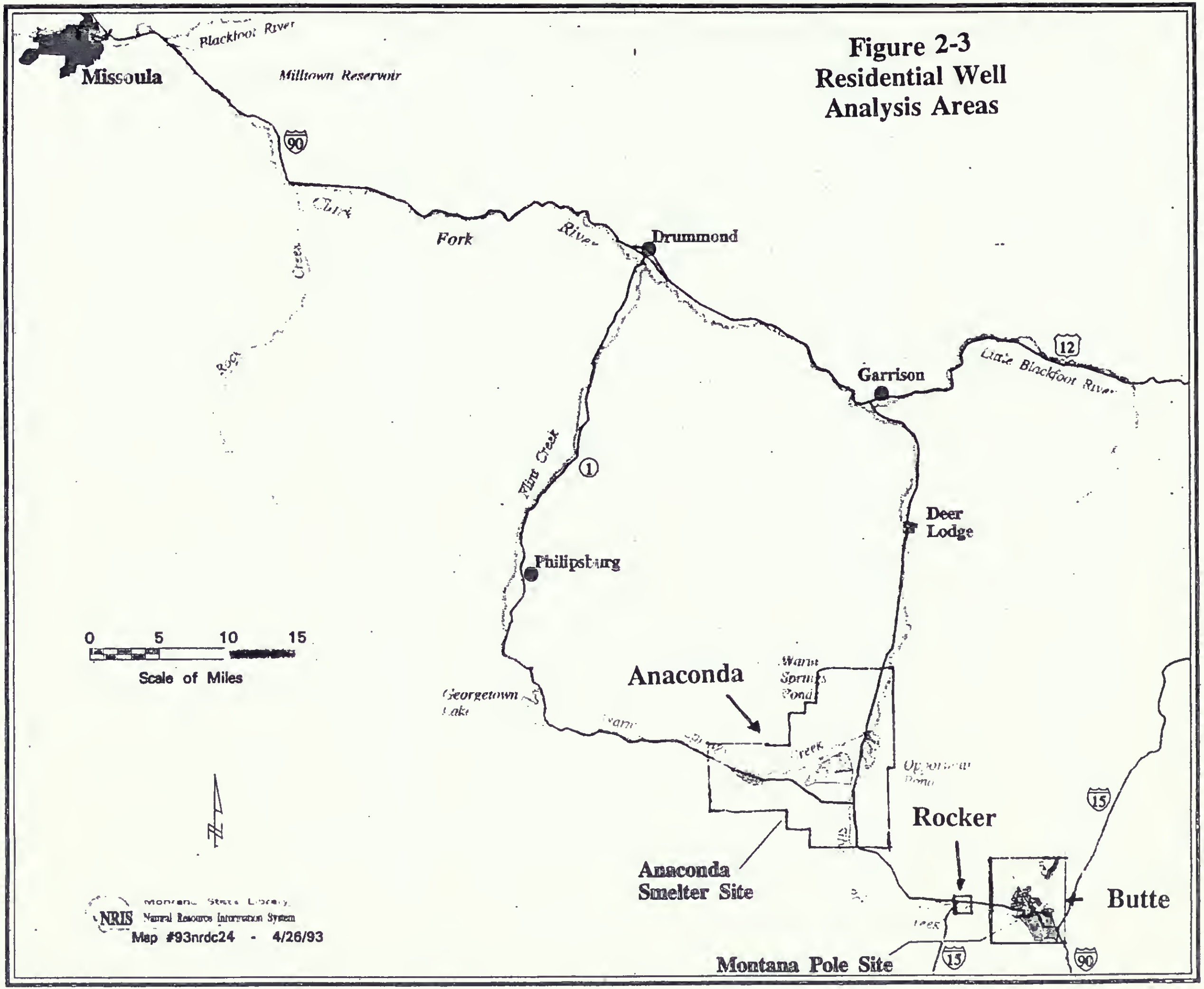

Figure 2-3
Residential Well
Analysis Areas

2.3.3 Average costs of residential groundwater wells

Table 2-7 shows the average specifications of the residential wells in the 3 analysis areas. Table 2-8 shows some statistics on the distribution of the variables shown in Table 2-7. It can be seen that most domestic wells are indeed 6" wells, with this size being much more predominate in Butte and Rocker than in Anaconda. Tables 2-7 and 2-8 also show that the average pumping depths for the three areas show quite a bit of variation.

Table 2-7. Mean values for domestic groundwater well specifications in the three analysis areas.

Variable	Anaconda	Butte	Rocker
Casing diameter (inches)	6.61	5.98	7.57
Total depth (feet)	53.20	89.95	114.08
Pumping level (feet)	47.83	63.28	99.87
Rated capacity (gallons per minute)	22.82	22.56	24.77
Top of casing level (ft. below ground level)	-1.58	-1.60	0.80
Bottom of casing level (ft. below ground level)	51.52	78.76	88.40
Sample size	403	170	36

Note: The sample size represents the number of wells in each area. Not all information was available on each well, however, thus the sample sizes on the individual statistics vary.

Table 2-8. Distribution of residential well characteristic variables in three analysis areas

Variable / Statistic	Anaconda	Butte	Rocker
% of 6 in. well casings	61.6	97.5	92.3
% of well yields between 10 and 30 Gallons per minute	50.0	76.0	48.0
Pumping Level			
% ≤ 200 feet	98.1	100.0	100.0
% ≤ 150 feet	96.1	95.7	75.0
% ≤ 100 feet	92.2	83.0	56.2
% ≤ 50 feet	73.8	51.1	31.3
Total Depth			
% ≤ 200 feet	98.1	94.0	94.3
% ≤ 150 feet	96.5	89.2	68.6
% ≤ 100 feet	90.9	69.9	51.4
% ≤ 50 feet	68.3	28.3	28.6
Sample Size	403	170	36

Table 2-9 details the calculation of average costs associated with delivering an acre foot of water to a residence in the analysis areas for a new well and in 1993 dollars. These costs were calculated based on average well depths and pumping lifts as well as two assumptions about the type of well installed. It was assumed for cost calculations that the wells would be 6" in diameter with standard steel casings. Table 2-9 shows that the costs associated with delivering groundwater for residential uses are dominated by the fixed costs of installing the well and pumping system. Pumps have an average life expectancy of 10 years nationally (personal communication, Mountain Supply, Missoula, MT). The costs of the well drilling and casing are amortized in perpetuity at a 7% real rate. The amortized costs of the well and pump per year are divided by the number of acre feet consumed per year by a residential customer (0.688, based on 1992-93 average consumption reported by Butte Water to the Montana PSC) to develop a cost per acre foot.

Table 2-9. Calculation of the average costs associated with delivering residential groundwater in the three analysis areas (1993 dollars).

Characteristic / cost	Anaconda	Butte	Rocker
Fixed costs associated with residential wells[a]			
Average total well depth Cost per foot of well depth	53.20 $18.00	89.95 $18.00	114.08 $18.00
Average cost of total depth	$957	$1619	$2053
Average cost of pumping equipment[b]	$1500	$1500	$1500
Average total fixed costs of well development and equipment	$2457	$3119	$3553
Amortized fixed costs per year of development and equipment (7.0%) for well and 10 year life for pump[e]	$202	$248	$279
Average fixed costs per acre foot pumped[c]	$293	$360	$405
Variable costs associated with residential wells			
Average pumping lift (feet)	47.83	63.28	99.87
Average electrical costs / ac.ft. pumped[d]	$10.60	$ 11.77	$14.54
Average total cost of well installation and operation per acre foot	$304	$372	$420

[a] Costs are based on a 6 inch well

[b] Based on a pump with a 25 gpm capacity and pressure tank.

[c] Based on estimated annual residential consumption of 224,400 gal per household.

[d] Based on average lift, 40 psi system pressure, 65% pumping plant efficiency, .048039/kwh electricity cost.

[e] Based on cost of total depth, plus non-pump equipment of $513, amortized in perpetuity at 7.0%, plus pump cost of $987 depreciated at straight line over 10 years.

Table 2-10 provides a comparison of average costs for a new household groundwater well compared to average current costs of municipal systems in Butte, Anaconda and Rocker. This analysis indicates that on average even a new household residential system would provide a cost savings compared to the municipal system average cost. Municipal system costs are, of course, long-run embedded costs.

Table 2-10. Comparison of residential average well costs and residential water prices (1993 dollars).

Statistic	Anaconda	Butte	Rocker
Municipal price per acre foot	$ 644.00	$ 1027.00	$ 1027.00
Less, average long term cost of residential well water production per acre foot	$ 304.00	$ 372.00	$ 420.00
Cost saving for groundwater resource for residential use, per acre foot	$ 340.00	$ 655.00	$ 607.00

The cost estimates associated with use of residential groundwater are based on several assumptions: average size and cost of the well and pumping system, average life of pump, amortization rate for fixed well costs, pumping plant efficiency, and average residential water use. The assumptions on efficiency and costs are, of course, specific to new wells. In older systems the pumping efficiency may be less than the assumed 65% and thus slightly raise the variable cost of water pumping. The amortization rate is based on current OMB guidelines (OMB Circular No. A-94).

The final assumption is that average residential water use is 25 ccf per month per household. This assumption is based on the average 1992-93 reported average hookup consumption for Butte. Additionally, this level of consumption is comparable to that seen in other Montana communities (for example Billings had an average monthly consumption from 1976 to 1990 of 25.7 ccf, see Table 2-3).

The cost savings estimates, shown in Table 2-10 are based on estimated current replacement costs for residential wells. This assumption understates the cost savings associated with the use of residential well water. In the absence of contamination these wells would likely have been drilled when the houses were built, at a significantly lower cost than current replacement costs. The use of historical well costs would be consistent with the use of current municipal water costs in Table 2-10 as current municipal costs are based on historical

imbedded costs. In the following section we address this issue of more accurately estimating residential well water costs based on historical, rather than current, well costs for the Butte area only.

2.3.4 Estimated loss to potential residential water users due to groundwater contamination

One method of estimating the aggregate loss to Butte residential water users due to contamination of the aquifer under Butte is to compute the amount of savings which residential water users would have accumulated had they been able to drill individual residential wells into the aquifer. For purposes of this analysis we are assuming that all households sited over the contaminated portion of the aquifer would have utilized private well water instead of municipal water in the absence of contamination.

There are more than 10,000 people living in the area of Butte which lies over areas of aquifer contamination. Additionally, there are 4,188 residential properties in this area (personal communication, Steve Blodgett, Butte-Silver Bow Planning Office). This analysis calculates the effect of contamination on the 4,188 residential properties. No attempt is made here to calculate the costs which groundwater contamination has imposed on the large number of commercial properties. The estimates presented here are therefore conservative in this respect. Examining only residential properties which are located over areas of contamination may be conservative in another way. Many houses which sit near, but not over, the contaminated plume may have made decisions not to drill residential wells due to uncertainty of the exact location of contamination or the possibility of the contamination migrating to their wells.

The calculation of estimated residential well water costs is based on the assumption that in the absence of contamination wells would have been installed when houses were built. The housing stock which sits atop contaminated portions of the aquifer was built previous to 1940 with many houses dating to 1910 and 1900 (personal communication, Stewart Kirkpatrick, Butte-Silver Bow GIS technician). We have made the conservative assumption that the residential wells in this area would have been drilled in 1940 in the absence of contamination. Further, we have assumed that the costs of well development associated with pumping and delivery equipment have paralleled the Producer Price Index of Finished Goods. Finally, we have used $7.00/ft drilling costs for the wells of a 1940 vintage (personal communication, Wes Lindsey, Lindsey Drilling). Based on these assumptions, Table 2-11 shows a breakdown of the component costs of residential wells for 1981 through 1993. These components include the amortized fixed costs of well drilling and pressure tank installation (depth cost estimated at $7.00/ft and pressure tank at $60.43, both amortized at a 7% rate), and depreciated pump costs for a 10 year life pump. It is assumed that it is equally likely that a pump will be replaced in any given year. Accordingly, amortized pump costs are derived based on the PPI and the 1993 pump cost of $987. The average amortized pump cost in any given year is equal to the cost five years previous. These total annual fixed costs of residential wells are divided by 0.688 to adjust for the number of acre feet consumed by the typical Butte residence in a year. The resulting fixed costs per acre foot are added to the variable electric pumping costs

of $11.77 (estimated using current residential rates which overstates electricity rates for previous years) to yield total cost per acre foot pumped for the average Butte residence utilizing the groundwater resource.

Table 2-11. Estimated cost of Butte residential groundwater well water supply: 1981-1994.

Year	Fixed drilling costs[a]	Pressure tank cost[b]	Pump cost[c]	Variable elec. cost/af[d]	Total cost/af[e]
1981	44.08	4.23	68.90	11.77	182.14
1982	44.08	4.23	73.32	11.77	188.56
1983	44.08	4.23	79.10	11.77	196.96
1984	44.08	4.23	87.94	11.77	209.81
1985	44.08	4.23	99.73	11.77	226.94
1986	44.08	4.23	108.91	11.77	240.28
1987	44.08	4.23	113.33	11.77	246.71
1988	44.08	4.23	115.14	11.77	249.34
1989	44.08	4.23	117.52	11.77	252.80
1990	44.08	4.23	118.65	11.77	254.45
1991	44.08	4.23	116.95	11.77	251.98
1992	44.08	4.23	119.45	11.77	255.60
1993	44.08	4.23	122.39	11.77	259.89
1994	44.08	4.23	122.39	11.77	259.89

[a] based on 1940 cost of $7.00/ft, 89.95 ft ave depth, 7% rate to perpetuity

[b] based on current pressure tank cost adjusted by PPI to 1940 cost, costed at 7% to perpetuity

[c] based on current pump costs adjusted by PPI

[d] from Table 2-9.

[e] The sum of columns 2-4 divided by .688 all added to column 5.

In order to estimate losses to residential water users, the present value of estimated losses from 1981 to 1993 were added to estimated future losses (based on present losses discounted forward into perpetuity). Past loss estimates are based on the difference between municipal

water costs in Butte and estimated residential well water costs for each year, compounded forward to 1994. Future losses are based on 1993 losses discounted into perpetuity at a 7% real interest rate. Table 2-12 shows the average metered residential water price, the estimated average cost of residential well water, the aggregate losses to 4,188 households, the present value of these past year losses, and total past year losses.

Tables 2-12 and 2-13 show estimated losses to Butte water users whose houses sit over the contaminated plume. All of these residences have been deprived of the option to install a personal well as an alternative to the more expensive municipal water supply. Total past and future losses to these water users are estimated to be approximately 45.4 million dollars. This estimate is conservative in that it considers only the additional cost of municipal water over personal well water and does not consider the lost increment of consumer surplus associated with paying the higher municipal rates.

Table 2-12. Calculation of total past and future losses to residential water users.

Year	Metered water rate[a]	Estimated well cost/af[b]	$ savings per household of well over city	lost savings for 4,188 households	PV (1994) of past year losses
1981	317.61	182.14	93.29	390,710	941,550
1982	378.56	188.56	130.85	547,985	1,234,168
1983	401.65	196.96	140.96	590,348	1,242,595
1984	410.28	209.81	138.05	578,164	1,137,336
1985	430.58	226.94	140.24	587,308	1,079,741
1986	459.53	240.28	150.99	632,342	1,086,482
1987	474.01	246.71	156.63	655,552	1,052,673
1988	479.19	249.34	158.29	662,918	994,861
1989	479.19	252.80	155.91	652,939	915,781
1990	479.19	254.45	154.77	648,180	849,632
1991	479.19	251.98	156.47	655,304	802,775
1992	479.19	255.60	153.98	644,863	738,304
1993	817.44	259.89	383.96	1,608,043	1,720,606
Present value of total estimated past year (1981-1993) losses					$13,796,505

[a] Average metered water rate derived from rate tariff sheets filed with Montana Public service Commission are based on an average estimated residential consumption of 25 ccf/month. [b] Table 2-11.

Table 2-13. Calculation of estimated future losses to residential water users and summation of total estimated losses to Butte water users (1993 dollars).

Year	Metered water rate	Estimated well cost/af	$ savings per household of well over city	lost savings for 4,188 households (1993 $)
1994	1,027.04	259.89	528.30	2,212,539
Present value of future lost savings (1994 losses discounted into perpetuity at 7% real interest rate)				$ 31,607,695
Present value of past losses				$ 13,796,505
Total estimated losses to residential water users				$ 45,404,200

3.0 Agricultural Water Values

3.1 Literature on Agricultural Water Valuation

Duffield et al. (1991) did a study of the values of surface water used for crop production in Montana and estimated the value of water to six crops in eight Montana counties. These estimates are appropriate for use in computing net groundwater values for agriculture in the Upper Clark Fork drainage. In order to convert these surface water values into groundwater values, it is necessary to subtract the average cost of getting the groundwater to the surface. To the extent that the surface water net values include conveyance costs that would not be associated with groundwater development, this approach understates groundwater values. Groundwater development costs include the amortized fixed cost of drilling the wells and installing the pumping equipment, as well as the variable costs of operation and maintenance of the wells. The acre foot values in Duffield et al. could be interpreted to represent the maximum value associated with groundwater (the case of natural artesian flow and little to no development costs).

Duffield et al. (1991) showed that agricultural water values are dependent, to a large extent, on the crop being irrigated, and the climate (or location) of the land being irrigated. The 1989 Montana Agricultural Statistics summary report shows the composition of crops grown in each Montana county. For the 1988 growing year Deer Lodge County reported 10,300 acres of crops of which 9,000 (or 87%) were either alfalfa or other hays. For Silver Bow County, there were 7,200 acres of crops planted in 1987 with 7,000 acres (or 97%) being either alfalfa or other hays. Since hays comprise the large majority of the crops grown in these two counties, the water values presented here will focus the value of water in the production of alfalfa hay.

Silver Bow county was not one of the 8 counties for which Duffield et al. 1991 estimated water values. As a proxy, the value of water in Deer Lodge County will be used for the estimation of alfalfa water values for Silver Bow County.

Table 3-1 shows the surface water values for the production of alfalfa in selected Montana counties as drawn from Duffield, et al. 1991. These represent the maximum value associated with groundwater use - the case of no pumping or development costs. The estimates are presented as a range of values in order to represent alternative conveyance efficiencies for the water from the well head to the crops. In the next sections these estimates are adjusted to account for the costs associated with developing the groundwater wells and delivering the water to the surface.

Table 3-1. Estimated net economic values of surface water associated with the production of alfalfa hay in selected Montana counties (1990 $).

County	Short run values			Long run values		
	25%[a]	50%	75%	25%	50%	75%
Beaverhead	19.77	39.54	59.30	16.35	32.71	49.06
Broadwater	12.94	25.88	38.81	10.64	21.28	31.92
Deer Lodge	18.73	37.46	56.18	14.09	28.18	42.27
Jefferson	13.59	24.17	40.76	10.28	20.56	30.84
Lewis & Clark	10.08	20.16	30.24	7.78	15.57	23.35
Meagher	10.85	21.70	32.55	7.43	14.85	22.28
Park	5.38	10.77	16.15	2.71	5.82	8.13
Ravalli	10.77	21.54	32.32	8.33	16.66	24.99

[a] Percentages represent typical alternative conveyance efficiencies.
Note: the values shown are for water used to center pivot sprinkler irrigate alfalfa hay.
Note: Short run values do not include costs of distribution equipment

The appropriateness of using the estimates shown in Table 3-1 as a base for calculation of groundwater values rests on the assumption that conveyance and application loss and conveyance and sprinkler system costs for surface water are appropriate for groundwater. If this assumption is valid then simply subtracting the costs associated with well installation and operation will yield the estimated net values of groundwater used in the production of alfalfa

hays. The most appropriate values as a starting point for groundwater valuation are the higher conveyance efficiencies (75%) shown in Table 3-1. The maximum values shown in Table 3-1 are therefore used in the following analysis.

3.2 Estimation of agricultural groundwater values

In this section the average costs of groundwater wells is computed to use in deriving a net value to agricultural use of groundwater. It is first necessary to identify the typical characteristics of agricultural groundwater wells in the Upper Clark Fork Valley. Dave Strufert, the County extension agent in Deer Lodge cited only one farm with a groundwater irrigation system in place in the entire Upper Clark Fork Valley (Powell, Deer Lodge and Silver Bow counties). This farm, along Racetrack Creek, uses groundwater to feed a center pivot irrigation system. It should be noted that there were 45 registered high volume wells, yielding greater than 500 gpm in this area. Only two of these, however, could be verified as being used for agricultural production. Because of the lack of groundwater irrigation wells in the area we limit our analysis of well costs to one general class of wells: a 500 gallon per minute 10 inch well.

Table 3-2 shows estimates of costs associated with groundwater wells used in agricultural production. Costs are shown for high volume systems operating at 500 gpm in a 10 inch well averaging 160 feet deep. The acreage irrigated by this flow is based on a minimum flow necessary of 7 gpm per acre (personal communication, Soil Conservation Service Office, Missoula). Table 3-2 also assumes that the wells are operated to capacity.

Table 3-3 shows the calculation of long run net values of groundwater used in the production of hays in the Upper Clark Fork drainage. The calculations assume that the crops are irrigated with a sideroll sprinkler system and that the total conveyance and application loss of water is 50%. This loss is not unusual for this type of system. Groundwater used in the production of alfalfa hay is estimated to have a net value of 17 dollars per acre foot. This estimate is based on 1990 crop prices and costs. Therefore, it appears that groundwater can be used as a profitable input to the production of alfalfa in Deer Lodge County.

Table 3-2. Average estimated costs associated with supplying groundwater for agricultural irrigation.

Characteristic / cost	500 gpm pump in 10" well
Fixed costs associated with agricultural wells	
Average total well depth	160
Cost per foot of well depth	$80.00
Average cost of total depth	$12,800
Average cost of pumping equipment	$7,000
Average total fixed costs of well development and equipment	$19,800
Amortized fixed costs per year of development and equipment (7.0%) for well and 10 year life for pump	$1596
Average fixed costs per acre foot pumped[c]	$11.16
Variable costs associated with agricultural wells	
Average pumping lift (feet)[e]	70.00
Average electrical costs / ac.ft. pumped[d]	$13.78
Average total cost of well installation and operation per acre foot	$24.94

[c] Based on estimated evapotranspiration rate for alfalfa hay of 12 inches and an overall irrigation conveyance and distribution system efficiency of 50%

[d] Based on average lift, 60 psi system pressure requirement and 20 psi friction loss, 65% to 75% pumping plant efficiency, 0.037/kwh electricity cost.

[e] Based on the average depth and pumping level of high volume wells in the analysis area

Table 3-3. Estimation of agricultural groundwater values for hay production in Deer Lodge County based on well costs and Duffield, et al. (1991) estimates of net water values to agriculture (1990 dollars).

Statistic	500 gpm well
(A) Alfalfa Hay	
Net long run value of water at the diversion (or well-head) in hay production for a system with sideroll sprinkler and 75% conveyance efficiency[a]	42.27
Long run well and operating costs	24.94
Net value per acre foot of groundwater	17.33

[a] Overall conveyance and application loss assumed to be 50%

3.3 Prices paid for surface water for agricultural use

Irrigation districts around the state which supply water to farmers for a predetermined price are one source of information on the value of water in Montana agriculture. An informal survey of several of these irrigation districts showed delivered water prices ranging from approximately $4 to $30 per acre foot. The majority of districts contacted reported water prices in the $4 to $6 /acre foot range. No irrigation districts were located in the Anaconda and Butte areas.

The price of water supplied by the irrigation districts to farmers is based on the imbedded cost of storing and delivering that water. Some irrigation districts use small containment reservoirs while other utilize onstream diversions as water sources. In general, the water cost to the farmer reflects the long term average imbedded costs of the irrigation district. The costs of new reservoirs or diversions would likely be substantially higher than the current typical irrigation district price of $4 to $6 /acre foot.

A comparison of the water charges, reported by the contacted irrigation districts, to the net long run value of water at the diversion (reported in Table 3-3) shows that the irrigation district charges are less than the long run value of water at the diversion for production of alfalfa. This is consistent with the fact that irrigators are willing to pay $4 to $6/acre foot for water from irrigation districts. Economic theory suggests that farmers will utilize water sources which do not cost more than the net long run value of that water at the diversion.

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